CS 103 Unit 11

Linked Lists

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NULL Pointer

- Just like there was a null character in ASCII = '\0' whose value was 0
- There is a NULL pointer whose value is 0
  - NULL is "keyword" you can use in C/C++ that is defined to be 0
  - Used to represent a pointer to "nothing"
  - Nothing ever lives at address 0 of memory so we can use it to mean "pointer to nothing"
- int* ptr = NULL; // ptr has 0 in it now
- if(ptr != NULL){ …   } // it's a good pointer

Arrays Review

- Arrays are contiguous pieces of memory
- To find a single value, computer only needs
  - The start address
    - Remember the name of the array evaluates to the starting address (e.g. data = 120)
  - Which element we want
    - Provided as an index (e.g. [20])
  - This is all thanks to the fact that items are contiguous in memory
  - If we know integer element i is at location 108 do we know where element i+1 is?

```
#include<iostream>
using namespace std;

int main()
{
  int data[25];
  data[20] = 7;
  return 0;
}
```

data = 100

100	104	108	112	116	120	
45	31	21	04	98	73	…

Memory

Limitations of Arrays

- We can dynamically allocate arrays once we know their size
- Example: Ask the user how many items they will need, then allocate an array for that size
- Problem: What if the user doesn't know how many they will create or simply changes their mind
  - Example:
    - cout << "How many numbers do you think you will input?" << endl;
      cin >> size;
      int *ptr = new int[size];
    - What if later the user wants to input an additional number??
    - Could allocate a new array of size+1 and copy items over but that becomes a time sink!
- Main point: Arrays, whether allocated statically or dynamically (using new), cannot be resized easily later on.

Analogy

- Natural analogy when we have a set of items that can change is to create a list
  - Write down what you know now
  - Can add more items later (usually to the end of the list)
  - Remove (cross off) others when done with them
- Can only do this with an array if you know max size of list ahead of time (which is sometimes fine)

```
1. Do CS 103 lab
2. Join ACM or IEEE
3. Play Video Games
4. Watch a movie
5. Exercise
```

~~1. Do CS 103 lab~~
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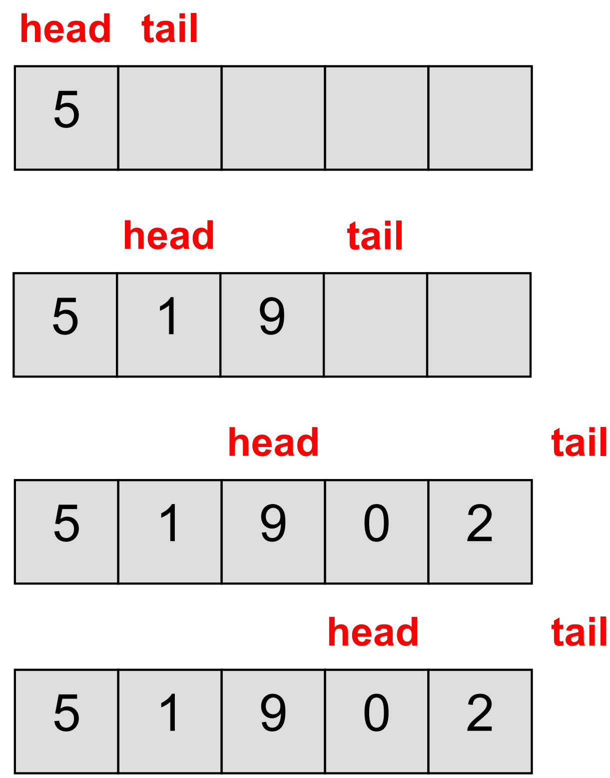
5. Exercise
6. Eat dinner

BFSQ Example

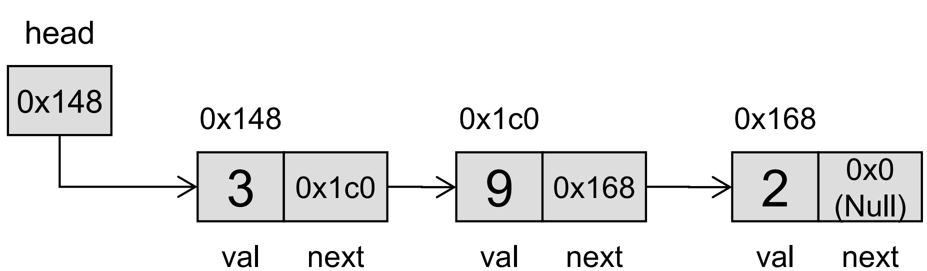
- The size of the BFSQ grew and shrunk based on the data pattern
- But we wasted a whole LARGE array planning for the worst case
- It'd be great to store only what we need where our storage can grow and shrink

.	.	.	#
#	S	#	#
#	.	#	F



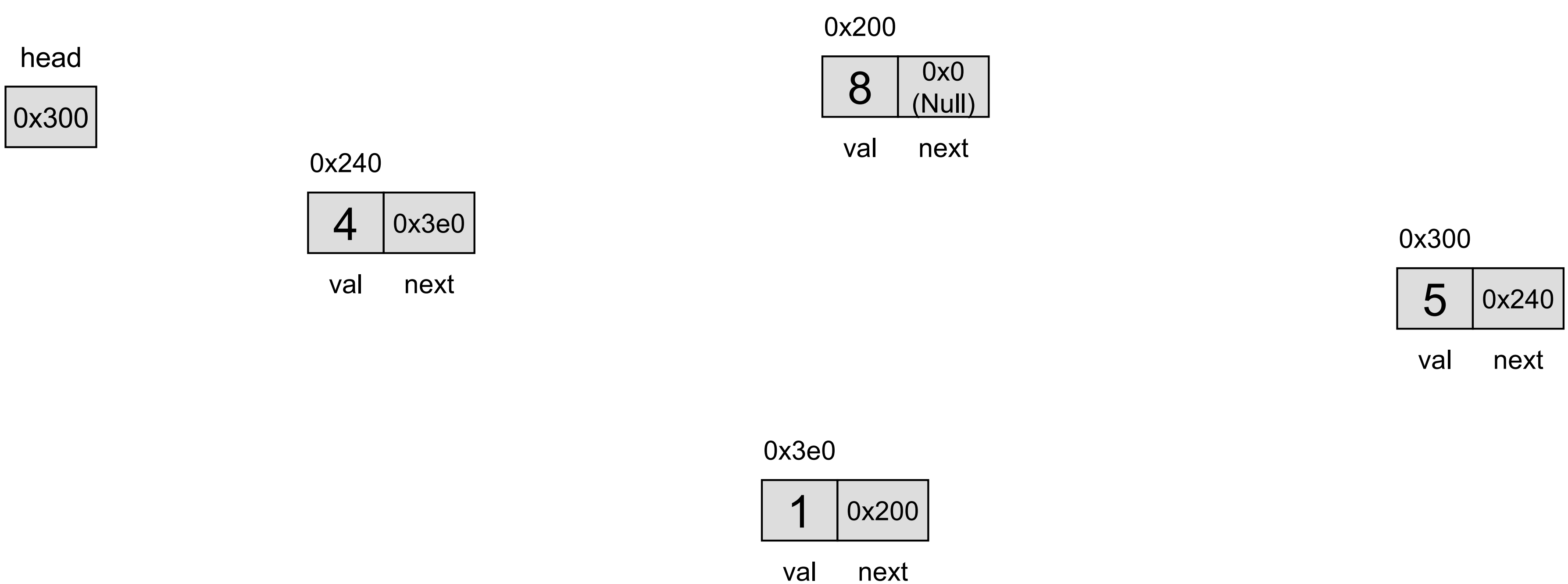
Linked Lists

- A linked list stores values in separate chunks of memory (i.e. a dynamically allocated object)
- To know where the next one is, each one stores a pointer to the next
- We can allocate more or delete old ones as needed so we only use memory as needed
- All we do is track where the first object is (i.e. the head pointer)



Linked Lists

- What is the order of values in this linked list?
- How would you insert 6 at the front of the list?
- How would you remove the value 4?



Arrays vs. Linked List

- If we have the start address of an array can we get the i-th element quickly?
  - Yes: start-addr + i * sizeof(data)
- If we have the start (head) pointer to a linked list can we find the i-th element quickly?
  - No…Have to walk the linked list
- Linked lists trade the ability to resize (grow/shrink) for speed of access when attempting to get a specific element

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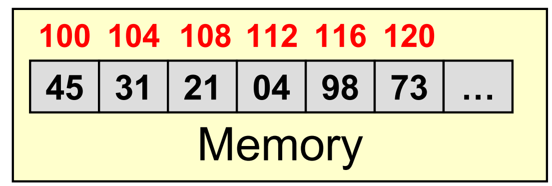

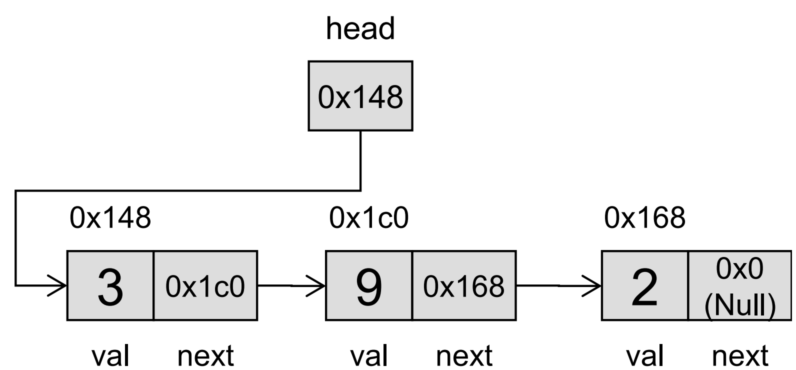

Linked List

- Use structures/classes and pointers to make 'linked' data structures
- List
  - Arbitrarily sized collection of values
  - Can add any number of new values via dynamic memory allocation
  - Usually supports following set of operations:
    - Append ("push_back")
    - Prepend ("push_front")
    - Remove back item ("pop_back")
    - Remove front item ("pop_front")
    - Find (look for particular value)

```
#include<iostream>

using namespace std;

struct Item {
  int val;
  Item* next;
};

class List
{
  public:
   List();
   ~List();
   void push_back(int v); ...
  private:
   Item* head;
};
```

struct Item blueprint:

int val	Item * next

class List:

head
0x0

Rule of thumb: Still use 'structs' for objects that are purely collections of data and don't really have operations associated with them. Use 'classes' when data does have associated functions/methods.

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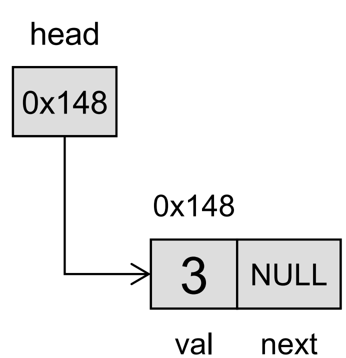
#include<iostream>
using namespace std;

List::List()
{
  head = NULL;
}
void List::push_back(int v){
  if(head == NULL){
    head = new Item;
    head->val = v; head->next = NULL;
  }
  else { ... }
}
int main()
{
  List mylist;
  mylist.push_back(3);
}
```



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int main()
{
  List mylist;
  mylist.push_back(3);  mylist.push_back(9);
}
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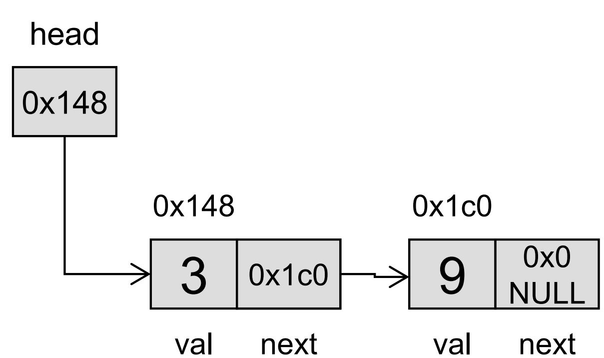

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    head->val = v; head->next = NULL;
  }
  else { ... }
}
int main()
{
  List mylist;
  mylist.push_back(3);  mylist.push_back(9);
  mylist.push_back(2);
}
```

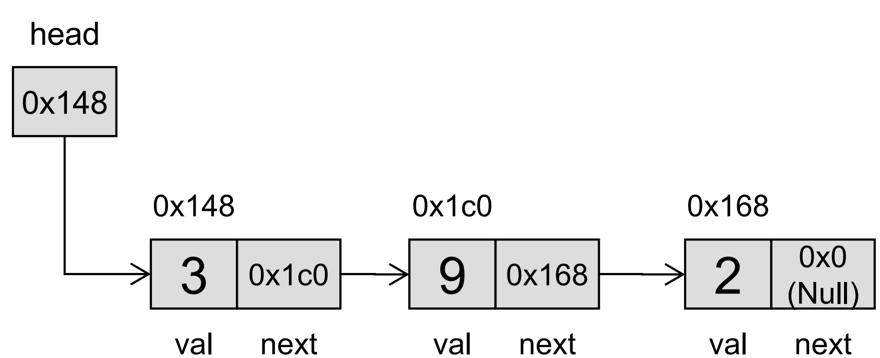

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  - Which element we want
    - Provided as an index (e.g. [20])
  - This is all thanks to the fact that items are contiguous in memory
- Linked list items are not contiguous
  - Thus, linked lists have an explicit field to indicate where the next item is

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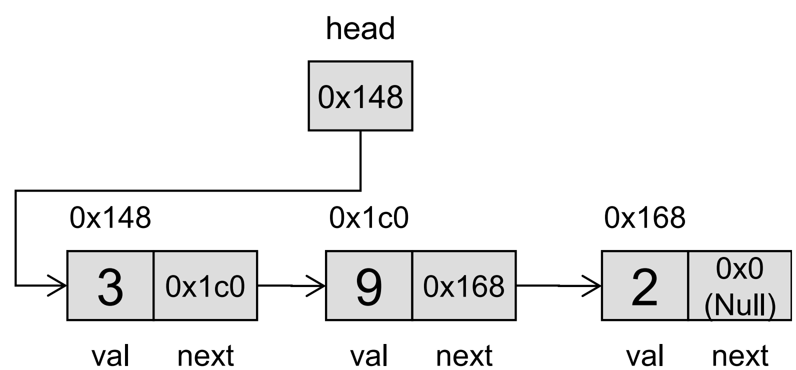
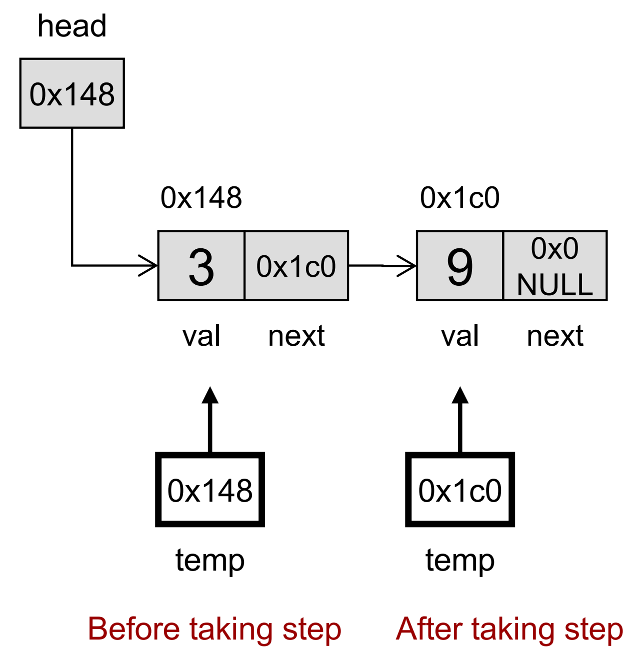
Memory



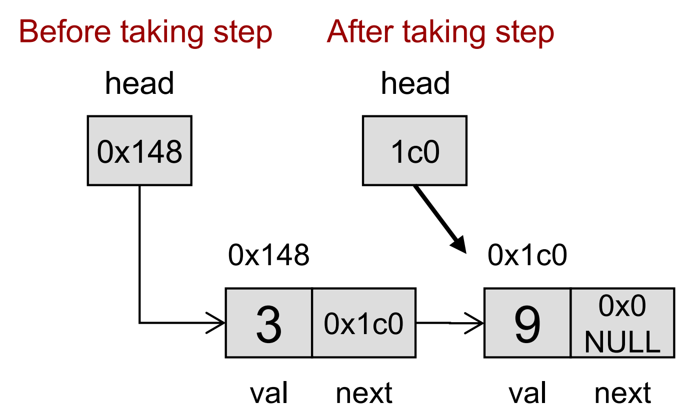
Common Linked Task/Mistake 1

- What is the C++ code to take a step from one item to the next
- Answer:
  - temp = temp->next
- **Lesson:** To move a pointer to the next item use: 'ptr = ptr->next'



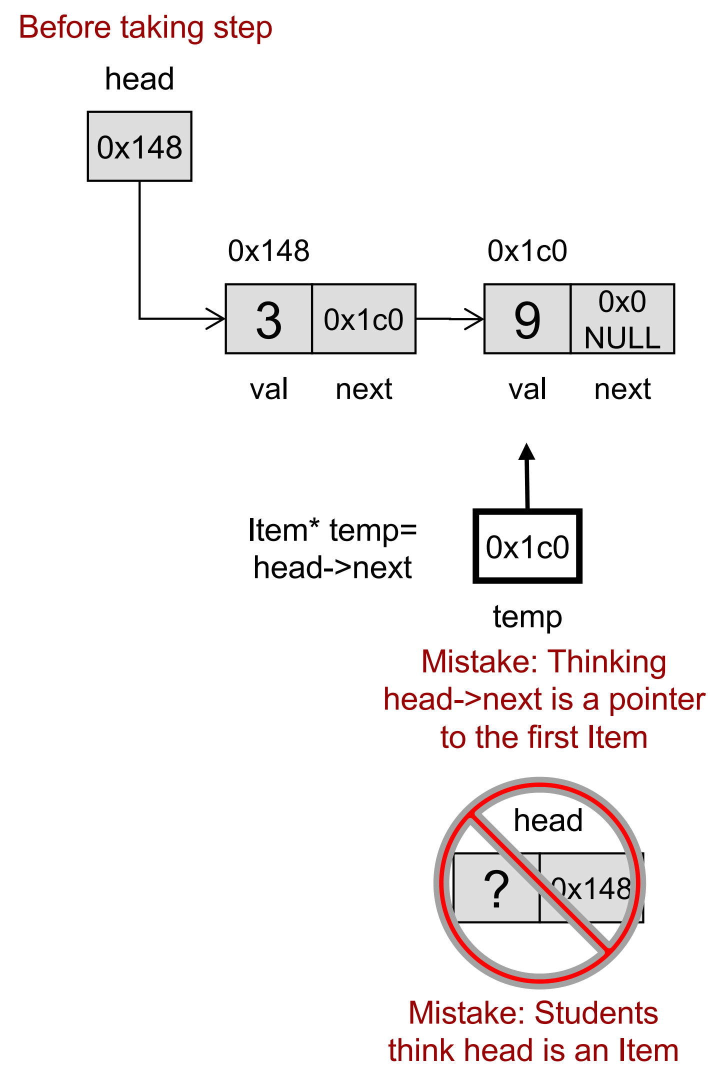
Common Linked Task/Mistake 2

- Why do we need a temp pointer? Why can't we just use head to take a step as in:
  - head = head->next;
- Because if we change head we have no record of where the first item is
  - Once we take a step we have "amnesia" and forget where we came from and can't retrace our steps
- **Lesson:** Don't lose your head!



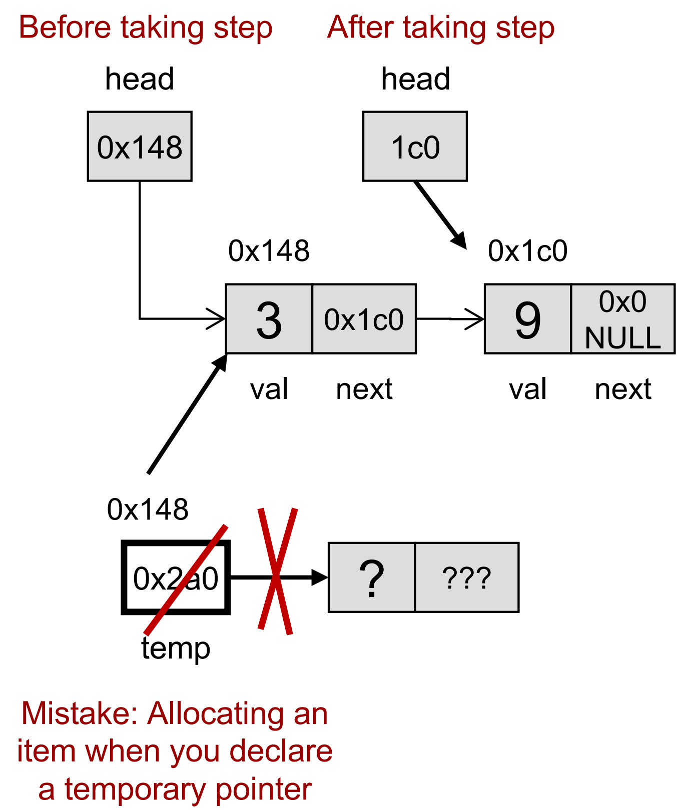
Common Linked Task/Mistake 3

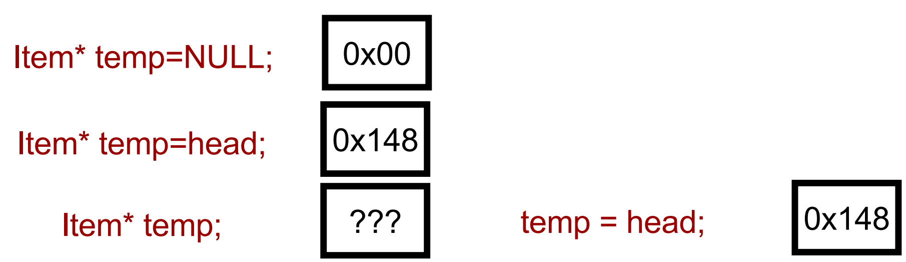
- Mistake: Many students use the following code to get a pointer to the first item:
  - Item* temp = head->next;
- head (or first) pointer is NOT an actual ITEM struct
- head is just a pointer
  - It is special in that it is the only thing that is not actually holding any data…it just points at the first data-filled struct
  - head->next actually points to the 2^{nd} item, not the 1^{st} because head already points to the 1^{st} item
- **Lesson:** To get a pointer to the first item, just use 'head'



Common Linked Task/Mistake 4

- Common errors we see is that to create a temporary pointer students also dynamically allocate an item and then immediately point it at something else causing a memory leak
  - Item* temp = new Item;
  - temp = head; or temp = head->next;
- You may declare pointers w/o having to allocate anything
  - Item* temp;
  - Item* temp = NULL;
  - Item* temp = head;
- **Lesson:** Only use 'new' when you really want a new Item to come alive





Exercises

- In-class exercises:
  - monkey_traverse
  - monkey_addstart

Childs toy "Barrel of Monkeys" let's children build a chain of monkeys that can be linked arm in arm

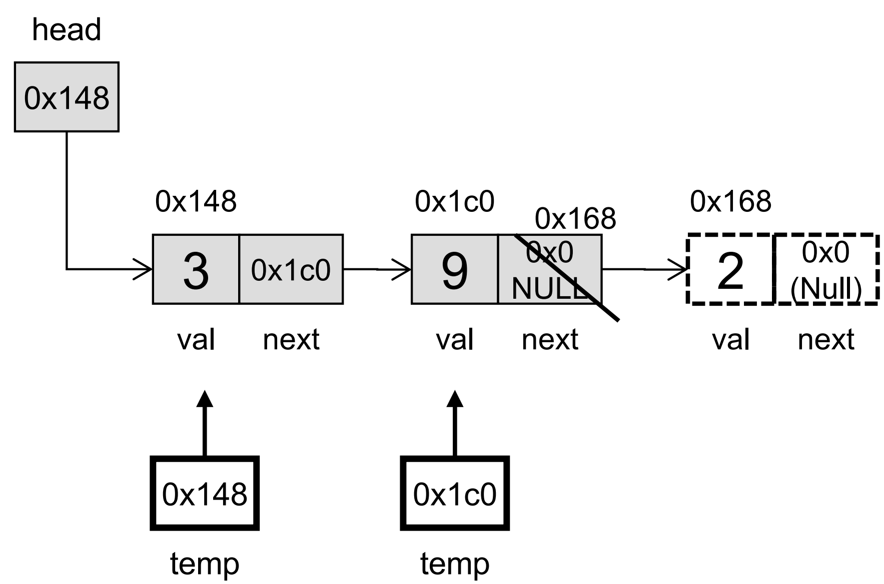
http://www.toysrus.com/graphics/tru_prod_images/Barrel-of-Monkeys-Game----pTRU1-2907042dt.jpg

Exercise

- Write an integer linked list class
- Download the skeleton:
  - Go to your `examples` directory
  - `wget http://bytes.usc.edu/files/cs103/listint.tar`
  - `tar xvf listint.tar`
    - `listint.h, listint.cpp, listint_test.cpp`
- Examine the prototypes in listint.h (complete)
- Complete the functions in listint.cpp
- Compile and test your program the code in listint_test.cpp

Append

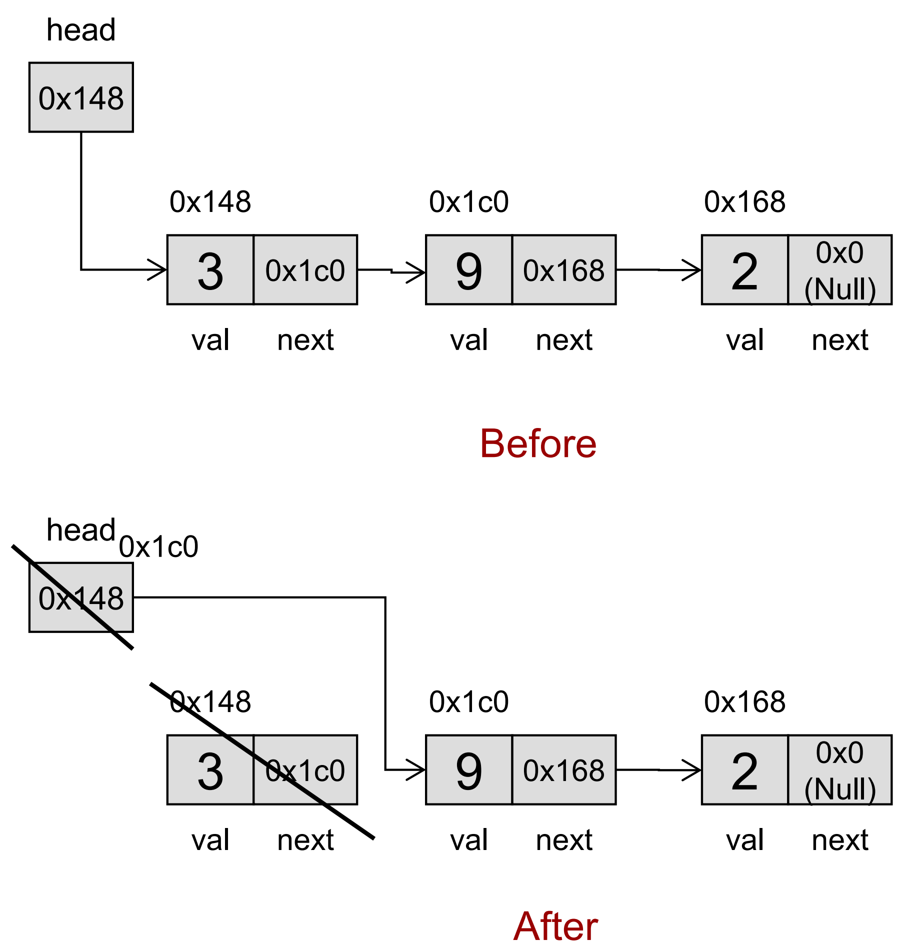
- Write a function to add new item to back of list
- Start from head and iterate to end of list
  - Copy head to a temp pointer
  - Use temp pointer to iterate through the list until we find the tail (element with next field = NULL)
  - Allocate new item and fill it in
  - Update old tail item to point at new tail item



I don't know where the list ends so I have to traverse it

Remove First

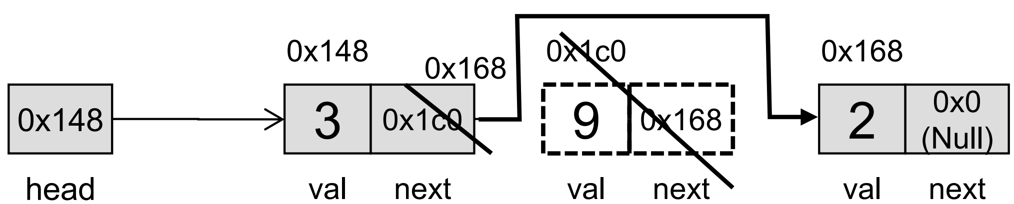
- Write a function to remove first item
  - Copy address of first item to a temp pointer
  - Set head to point at new first item (only second item)
  - Deallocate old first item



Other Functions

- Write a function to print all items in list
  - Copy head to a temp pointer then use it to iterate over the items until the next pointer is NULL
  - Print each item as you iterate
- Find if an item in the list (return address of struct if present or NULL)
  - Copy head to a temp pointer then use it to iterate over the items until you find an item with the desired value or until next pointer is NULL
- Remove item with given value [i.e. find and remove]
  - If found, need to change the next link of the previous item to point at the item after the item found

Remove
VAL=9



Comparing Performance

Arrays

- Go to element at index I
  - O(1)
- Add something to the tail (assume you have a tail index)
  - O(1)
- Adding something to the front of the list after there are already n elements
  - O(n)

Linked Lists

- Go to element at index i
  - O(i)
- Add something to the tail (assume you have only head pointer and n elements in the list)
  - O(n)
- Adding something to the front of the list after there are already n elements
  - O(1)